PROJECTS

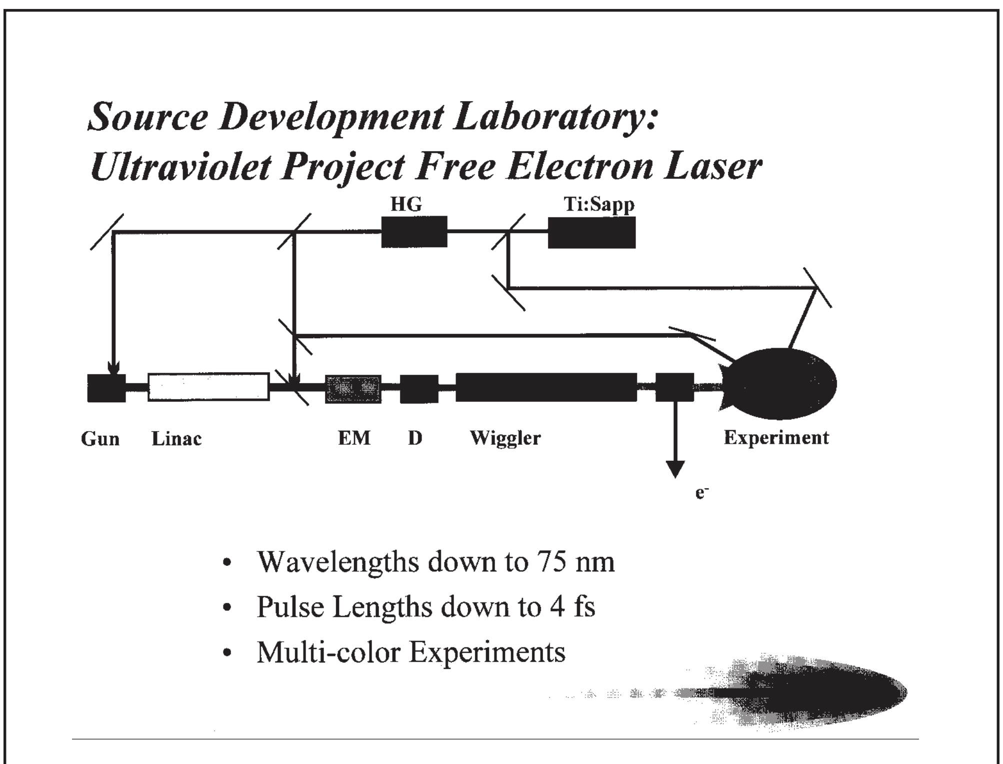
THE NSLS SOURCE DEVELOPMENT LABORATORY

Erik D. Johnson
SDL Project Manager

The Source Development Laboratory (SDL) was created as a project within the National Synchrotron Light Source as a way to serve its user community by developing sources for the next generation of synchrotron radiation based research. The path to the founding of the current SDL was based on a strong interaction between potential users of advanced sources of light, and the NSLS. It is possible due to innovative developments in accelerator physics by NSLS staff and experimental achievements at the Accelerator Test Facility (ATF). Another element that makes the SDL so readily possible is the wealth of infrastructure and equipment already available.

The focus of the SDL is on joint development of both the radiation source and science program based on its capabilities. Generally speaking, the project is developed to fit within the framework of research supported by the DOE office of Basic Energy Sciences. It's sister facility, the ATF, provides significant accelerator expertise employed by the SDL. However the active beam physics experimental program of the ATF precludes its use as a UV FEL source for research. Throughout the SDL project, we have made every possible effort to draw on existing resources and the strengths of collaborators from many interested institutions.

Early on in the process of evaluating alternative source technologies, the vacuum ultraviolet was identified as a promising area for development. Although there are many FEL projects in the world, to date, all the successful user facilities have been based on oscillator designs. This places very great demands on the optical elements of the cavity in terms of reflectivites which would be difficult to routinely achieve in the ultraviolet. An alternative approach would be to run a high current electron beam through a long undulator in a single pass. Many projects have been started based on this Self Amplified Spontaneous Emission (SASE) or startup from noise model.



While SASE may get to shorter wavelength without oscillator optics, it is essentially amplification of noise which, from the standpoint of users of the radiation, may have serious experimental consequences. For this reason, Li-Hua Yu and his collaborators have developed the approach adopted at BNL for creating a seeded amplifier FEL. In addition to providing superior stability, this approach allows the generation of high harmonics of the fundamental radiation used for the seed. This means a visible seed laser (and its properties) may be amplified and frequency multiplied, in principle, well into the ultraviolet.

The figure gives a qualitative picture of how the SDL FEL works, and provides some insight into its potential power as an experimental tool. A "conventional" Ti:Sapp laser system is frequency multiplied to stimulate emission of electrons from the cathode of the RF gun. This gun provides a high peak current, low emittance pulse of electrons which is accelerated by a SLAC type S-band linac. For seeded beam operation, these electrons pass through an energy modulation wiggler (EM) while interacting with a portion of the laser beam from the laser driving the photocathode. In the seeding process an energy modulation is introduced on the electron beam which is converted into a spatial modulation by a dispersive magnet (D). The already microbunched beam is introduced to the amplifier wiggler which may be tuned for gain either at the fundamental seeding energy, or a higher harmonic.

This arrangement can be readily viewed as essentially a high gain amplifier and frequency multiplier for the seed laser. The FEL output will then reflect characteristics of the seed laser such as wavelength, pulse length, bandwidth and energy chirp. This property makes the seeded beam FEL a very high quality tool for research applications requiring stability and short wavelengths. For our long term goal, we have our sights set on performing experiments with an FEL producing UV radiation at wavelengths below 100 nm in pulses as brief as 5 fs with peak power ranging to over 100 GW. There are, of course, a few intermediate steps that need to be taken.

We are working hard on bringing up the SDL accelerator now, and are hoping to have the linac operational in mid 1998. The FEL experiments will come as rapidly after that as time, determination, and budget allow. As the effort has intensified a great deal of work must be pursued in parallel. To make this possible we have formed a management team.

Jim Desmond and Nick Gmür are responsible for finding ways to make sure the project gets done with the budget we have, and meets all the requirements to run in a safe manner; no small tasks these days. For the other team members, the project areas listed are really an inadequate representation of the wide range of contributions and responsibilities within this small project. For example, in addition to specifying and commissioning the SDL Laser systems, Lou DiMauro (with his joint appointment in Chemistry) brings his expertise in atomic physics and the broader knowledge of conducting experiments with lasers to the project. Besides developing new diagnostics and coordinating the rebuilding of the accelerator control system, Bill Graves did extensive simulations of the compression system and beam transport. Through this work, he developed the current linac design that includes pulse compression and a focused interaction point for Thompson scattering studies; enhancements that significantly extend the potential of the machine.

Richard Heese brings extensive experience in linac technology and development to the project. He has also assumed the responsibility for supervising the reconstruction and upgrade of the SDL linac and has taken on the difficult task of coordinating the technical work in bringing the facility up. Xijie Wang brings not only the gun technology to the project, but his experience of coordinating the operation of the ATF. Li-Hua Yu not only developed the basic physics for our planned FEL, he is leading the High Gain Harmonic Generation (HGHG) experiment at the ATF and applies his experience to the development of the SDL program.

We also have a project advisory panel, consisting of Ilan Ben-Zvi, Jerry Hastings, and Sam Krinsky who bring a broad perspective to the problems of bringing up a new accelerator based source. In actually accomplishing anything, the broad participation from every section of the department has been critical. This has been especially true of the electrical and mechanical groups who are responsible for the majority of the visible progress to date. All in all people have been attacking their tasks with an enthusiasm that lifts the whole project. We hope to be seeing some of that work coming to fruition in the next year. To look at the project in more detail or to keep abreast of the latest developments, visit the SDL web page http://www.nsls.bnl.gov/BeamRD/Erik/SDL.html. ■

The SDL Management Team

The following individuals are bringing their expertise to the task of bringing the SDL "on-line".

Jim Desmond	Fiscal Management
Lou DiMauro	Laser Physics
Nicholas Gmür	ES&H
Bill Graves	Diagnostics & Controls
Richard Heese	Linac Systems
Erik Johnson	Project Manager
Xijie Wang	Electron Gun Systems
Li-Hua Yu	FEL Physics

PROJECTS

The Accelerator Test Facility

Ilan Ben-Zvi
ATF Head

The interest in Free-Electron Lasers operating in very short wavelengths, down to hard x-rays, is growing. Recently a team of NSLS, MIT, Columbia and Berkeley scientists made a measurement that is deemed important in this context. In the following I will try to provide the background for this measurement that was made at the BNL Accelerator Test Facility.

A key aspect of the mission of Brookhaven National Laboratory (BNL) is to construct, operate and use large facilities for the breadth of scientific disciplines supported by the Department of Energy. An important component of the success of BNL comes from innovative accelerator R&D, since new accelerator technologies hold the key to new achievements in applications and user facilities. We are facing now the emergence of a new technology, that of very high-brightness electron beams. This technology has far reaching implications for x-ray sources and other applications.

Part of the mission of the National Synchrotron Light Source is to develop radiation sources for the future. The NSLS has been the first light source to pursue the development of Free-Electron Lasers as the next generation synchrotron light sources. BNL has been a leader in the national effort on FEL development, hosting the workshops "Prospects of a 1 Å FEL" in 1990 and "Towards Short Wavelength FELs" in 1993, as well as developing its Conceptual Design Report and pursuing subsequent efforts to develop a national collaboration in the field. In the past decade, the NSLS made significant contribution to the science of FELs like the theories on Universal Scaling of exponential regime FELs in 3-D, the High-Gain Harmonic Generation and beam conditioning. Experimentally we have led in the development of record high-brightness electron beams and methods of measurements of these and, as has been hinted at earlier, the shortest wavelength measurement of Self Amplified Spontaneous Emission (SASE).

FELs can provide an important tool reaching beyond the capabilities of high brightness synchrotrons. Science that explores non-linear effects at short wavelength, dilute systems or intensity correlation studies, require high peak power and will only become possible when appropriate sources, such as FELs, are available.

The NSLS developed a vision of the next generation of light sources and is assembling the beam physics and technology to make this happen. Emphasizing single-pass FEL amplifiers, which have advantages over oscillators in the short wavelength regime where cavity mirrors are unavailable, the NSLS developed the High-Gain Harmonic-Generation (HGHG) FEL approach as a the best strategy to build a high quality short wavelength FEL. High-brightness electron beams R&D was undertaken in a major way, since this is the key to achieving short-wavelength FELs as well as other significant applications, such as linear colliders, laser accelerators and more. The BNL Accelerator Test Facility (ATF) is the proving ground for these advances.

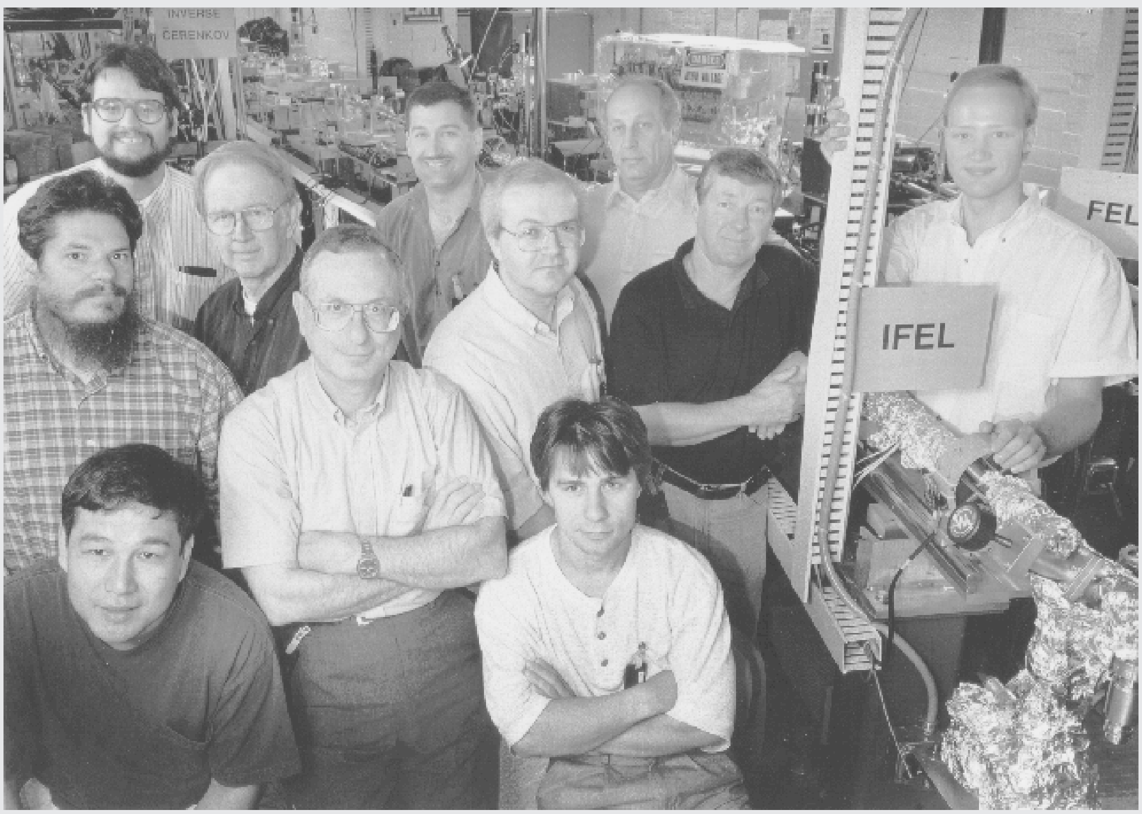
What is the ATF? First and foremost, it is a User's Facility for accelerator and beam physicists, operated by the NSLS and the BNL Center for Accelerator Physics. There is no other proposal-driven, peer-reviewed facility like the ATF that is dedicated for long range R&D in accelerator and beam physics.

The ATF has a unique combination of a high-brightness electron beam, synchronized-high-power lasers, a well-equipped 3 beamline experiment hall, and advanced diagnostics and control systems. The ATF's program in RF guns is recognized internationally. With its synchronized lasers and electron beams of unprecedented brightness, the ATF is an ideal site for R&D on advanced accelerator concepts, FELs, femtosecond X-ray sources and similar topics. These tools have been crucial to recent ATF record achievements: the measurement of Self Amplified Spontaneous Emission (SASE) at 1 μm and 0.63 μm, and laser acceleration by the Inverse Cerenkov and Inverse FEL mechanisms.

The generation and acceleration of very high brightness electron beams is a key technology for short wavelength FELs as well as other applications, including linear colliders, Compton backscattering for the production of femtosecond x-rays, laser accelerators and more. A high brightness means that the electron bunch has a high density in 6-D phase space. To achieve high brightness beams, it is necessary to master the production of such beams in special electron guns, to develop diagnostics that provide information of the 6-D distribution of electron bunches on sub-picosecond time scales, to control the 6-D distribution of the bunch in various ways and to be able to accelerate the electrons to high energies without diluting the brightness.

NSLS scientists working at the ATF measured the slice emittance of a 10 ps electron bunch with a 1 ps resolution, achieved an unprecedentedly high 6-D electron phase-space density and directly measured electron bunching on an optical scale. Another diagnostic under development at the ATF is tomographic analysis of the distribution of electrons in transverse phase space. The next step is to pursue non-linear emittance compensation. Laser photocathode RF guns have provided a major improvement in the brightness, which was further enhanced by the introduction of (linear) emittance compensation. The dream of another major improvement by the introduction of non-linear corrections has been brought within reach by the development of the slice-emittance diagnostic and the availability of lasers with longitudinal pulse shaping.

Key to our plans is the development of sub-harmonically seeded FELs in which harmonic generation converts a laser seed to much shorter wavelength radiation. A proof-of-principle High-Gain Harmonic-Generation (HGHG) FEL experiment is planned to be carried out at the ATF in the infrared using a CO_2 laser seed. Both the SASE and HGHG work will be extended into the VUV at the SDL, using the NISUS wiggler. These experiments at the ATF and the SDL are milestones, not just for the BNL program, but also for other projects like the proposed



(Top, from left to right) John Skarita (Mechanical Section), Marc Montemagno (Electronics), and Igor Pogorelsky (Lasers).
(Middle, from left to right) Bob Harrington (Mechanical and Optical Systems), Joe Sheehan (Electrical Section), Robert Malone (Computer and Control), Bill Cahill (Technical Supervisor and Users' Coordinator), and Marcus Babzien (Lasers).
(Bottom, left to right) Xijie Wang (Accelerator, gun, diagnostics), Ilan Ben-Zvi (Head of ATF), and Vitaly Yakimenko (Accelerator, gun, diagnostics).

Linear Coherent Light Source at SLAC and the Tesla Test Facility FEL at DESY, Hamburg. The goal of these efforts is basic experimental research in FEL physics, which has been recommended by numerous panels and review committees as an imperative on the way to developing short wavelength FELs. An initial success in this program has been the ATF measurement of SASE at 1μm and 0.63 μm. At the SDL, it is planned to utilize the output of the FEL to carry out prototype experiments to gain experience in providing FEL beams to users.

One of the special features of the measurement at the ATF is that the short wavelength was reached at a relatively low electron beam energy (34 MeV for the 1 micron measurement). To get gain with an FEL at a lower energy, the beam emittance must be small. It is easy to show that the beam energy required for obtaining a particular FEL wavelength is proportional to the beam emittance. The wiggler length is proportional to something between the emittance and the emittance squared, depending on the wiggler strength parameter. Since the complexity and cost of an electron linac and a wiggler are proportional to the length of these devices, an improvement of one order of magnitude in the electron beam emittance will reduce the cost by one order of magnitude! Such a reduction has taken place in the last decade with the introduction of emittance compensation techniques to laser-photocathode RF guns, and that is the driver behind the recent activity in short wavelength FELs. Another order of magnitude will place an x-ray FEL within reach of every laboratory.

Another feature, made necessary by the low energy, is the use of a very short period undulator. It is clear that to make use of lower emittance electron beams short period undulators must be developed. The SAE measurement at the ATF was made with an undulator built by MIT with a period of 8.8 mm. Another undulator, with the same period but using a superconducting magnet, was developed by the NSLS. These are the shortest period undulators in actual use anywhere.

The ATF and the NSLS are in the center of the national effort to develop short wavelength FELs, and effort that at this time encompasses also SSRL, APS, TJNAF and universities. Whenever possible, we have collaborated with other laboratories, as exemplified by the highly successful “Next Generation Photocathode RF Gun” developed with SLAC and UCLA, the SASE and HGHG experiments at the ATF being developed with ANL using a wiggler from Cornell, as well as collaboration with industry. In the near future, an exciting new experiment is being proposed for the ATF. This is the VISA experiment (short for Visible SASE). It is planned as a collaboration of BNL (NSLS), UCLA, SLAC (SSRL), LLNL and LANL. In this experiment a four meter long wiggler with a period of 1.8 cm will be installed at the ATF to produce SASE to saturation at visible wavelengths. This experiment is considered by SSRL as an important milestone on the way to a hard x-ray FEL. Following the experiment at the ATF the wiggler will be increased in length to six meters and installed at the SDL to extend the experiment to the VUV at about 100 nm.

The FEL community is aware of the large gap that exists between the wavelength at which SASE has been demonstrated and the goal of sub nanometer wavelengths. Until recently the gap was 7orders of magnitude. The consensus reached at many professional workshops and reviews on the subject of short wavelength FELs is that in order to bridge this gap in FELs, a series of experiments at increasingly shorter wavelengths must be undertaken. UCLA and Los Alamos have recently made a good SASE measurement at 12 microns, closing the gap to five orders of magnitude. The ATF measurement closed it to four orders of magnitude and we may expect new records to follow, until x-ray wavelengths will be reached. ■